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# RADAR LOCATION OF PLANET MERCURY

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# RADAR LOCATION OF PLANET MERCURY *

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Radio or radar location of planet Mercury was carried out in June 1962 by the Institute of Radio Technology and Electronics of the USSR Academy of Sciences in collaboration with a series of organizations. Mercury's lower conjunction was selected for measurements, when the planet is closest to Earth. During measurements the distance to Mercury constituted 83 to 88 million km, and was twice greater than at radar location of Venus in 1961 [1].

The study was carried out in a frequency near 700 mc/s. The transmitting antenna had a circular polarization. The density of the power flux at emission was 375 megawatt/sterad. Because of great distances and small dimensions (since the surface of Mercury is six times smaller than that of Venus) only about 1 watt hit the total visible surface of Mercury. The transmission was carried out by about 10-minute sessions, during which the signal passed the distance from Earth to Mercury and return. The transmitted signal

* RADIOLOKATSIYA PLANETY MERKURIY.

had the form of telegraph dispatchings alternating in two frequencies and differing by 62.5 cps. The duration of dispatchings and pauses in each frequency was of 1024 milliseconds.

The reception of reflected signals was made on an antenna with linear polarization. A paramagnetic and a parametric amplifier were installed at the receiver's input. The reflected signals originating together with the noises at receiver's output in the 30 to 300 cps frequency band and with a scale oscillation of 2000 cps were registered on a magnetic tape. The beginning of registration of 2000 cps oscillations corresponded to the computed moment of arrival of the 10-minute series of reflected signals.

The shift of carrier frequency and of frequency of reflected signal manipulation, caused by the Doppler effect on account of the motion of Mercury and of the Earth (taking into account its rotation) was compensated according to a computed program with the aid of a special device linearly varying the frequency by 0.2 cps steps in the course of a session. At the same time, the astronomical unit was taken equal to $A = 148\,599\,300$ km [1], and the speed of light — to 299 792.5 km/sec.

The energy distribution in the spectrum of the registered oscillations was investigated with the aid of a 20-channel analyzer, similarly used in 1961 for Venus radar location [2, 3]. Two-circuit band-pass filters were used in the analyzer, with a 16 cps pass-band width (along the 3 db level), whose mean frequencies differed by 16 cps.

Owing to the fourfold increase in magnetophone velocity when reproducing by comparison with the registration (which caused a proprtional widening by 4 times of the frequency spectrum of registered oscillations) the analyzer channel's pass-band width, converted to the received signal, was of 4 cps.

The principle of energy measurement of reflected signals is illustrated in Fig. 1. Figured in the same drawing is the variation of the instantaneous signal and noise power E' (t) and E" (t) in the two channels of the analyzer, whose frequencies differ by 62.5 cps. At time of magnetic recording reproduction at the output of each of the analyzer channels the aggregate signal and noise energy (see Fig. 1 for the designations) is determined for the even and odd half periods of manipulation frequency with T/2 = 1024 millisecond duration, and the difference energy is computed:

$$\Delta W_\tau = \Big( \sum_{1,3,5,\ldots} w_i' - \sum_{2,4,\ldots} w_i' \Big) - \Big( \sum_{1,3,5} w_i'' - \sum_{2,4} w_i'' \Big). \qquad (1)$$

This quantity depends on the time lag $\tau$, established at time of magnetic recording reproduction. Assume that the lag $\tau$ is chosen such that the moment $t + \tau$ correspond precisely to the factual time of reflected signal serie arrival. In this case the signal hits one of the channels at odd intervals, and the other, whose frequency is 62.5 cps less, — at even intervals. In the first channel the aggregate energy for the odd intervals is equal to the energies of signal and noise, and for the even intervals — only to noise energy. The inverse takes place in the second channel. The obtained quantity $\Delta W_\tau$ is maximum in this case and as an average equal to the energy of reflected signals reaching both channels. The obtained values of $\Delta W_\tau$ were related to the greater frequency.

The sensitivity calibration of the radar installation was made by the emission of the extra-terrestrial discrete source Cassiopea A. Between 10 and 15 June 1962 materials of 53 sessions were processed.

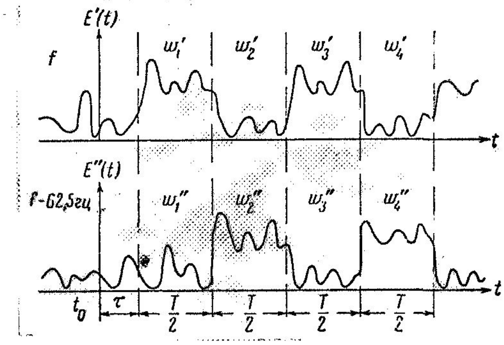


Fig. 1. Time diagram of analyzer operation; E' (t), E" (t) are respectively the instaneous power of the received signal in the first and second channels, whose frequencies differ by 62.5 cps. T is the period of signal manipulation ( 2048 milliseconds); $w'_i$ и $w''_i$ are respectively the energies of the signal and the noise for T/2 interval duration in the first and 2nd channels; $t_0$ is the moment of the beginning of 2000 cps oscillation registration on the magnetic tape; $\tau$ is the lag, fixed by the operator at time of reproduction of magnetic registration.

The aggregate result of measurement of the spectrum of Mercury-reflected signals is plotted in Fig. 2. Here the values of frequency setting of analyzer f channels are in the abscissa, and the sum of difference energies (1) for the processed sessions, converted to power S flux density as received by the antenna is plotted in ordinate axis. Dashed line points to the magnitude of the mean-square error caused by the noises.

If the astronomical unit corresponds to the value 149 599 300 km admitted by us, the signal energy must accumulate in case of blurring of the spectrum during all days in channels corresponding to signal's nominal frequency of 215 cps. This is exactly what was obtained, as may be seen from Fig. 2.

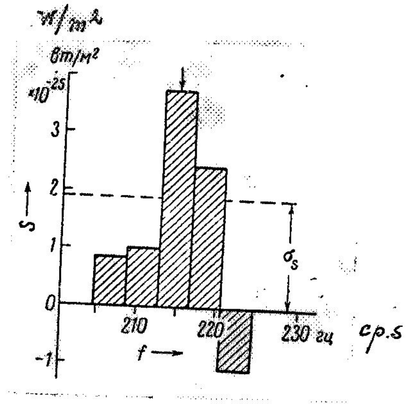

Fig. 2. Mean spectrum of Mercury-reflected signals (10 to 15 June 1962).

The energy of the central band 4 cps wide in Fig. 2 corresponds to the power of the reflected signal — 0.035 watt, isotropically scatterd by Mercury's surface. Since about 1 watt hit the total surface of Mercury in these measurements, the mean reflection factor for this band results to equal to 3.5%. When adding up the energies in the 12 and 20 cps frequency bands (respectively 3 and 5 bands in Fig. 2) *, Mercury's reflection factor is obtained equal to 6%. These results are close to the data on the Moon, known to us. According to radar measurements [4, 5] the reflection factor of the Moon constitutes 2 ÷ 7.5%, while half of the energy of reflected signals is concentrated in a frequency band near 2 cps (converted to Mercury) [6].

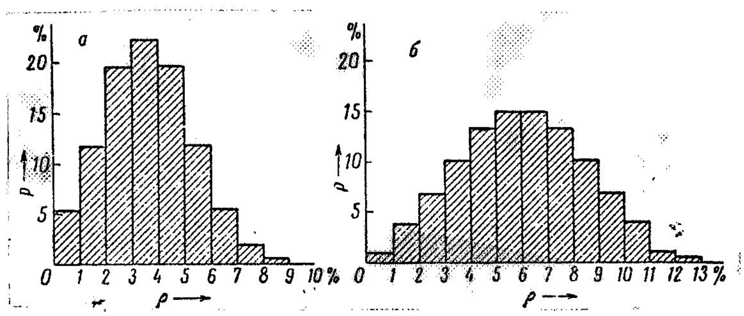

Fig. 3. Distribution of the probabilities of reflection factor values by the energies in the 4 cps (a) and 12 cps (b) frequency bands.

* see infrapaginal note next page

Inasmuch as it is not possible to reliably establish Mercury's reflection factor in view of the low signal-noise ratio, the results of measurement are presented in Fig. 3 in the form of likely histograms. Plotted is in the abscissa axis the value of the reflection factor $\rho$ with a 1% interval, and in the ordinate axis — the probability p that the true value of the reflection factor is in the given interval. At the same time it was estimated that the a priori density distribution of reflection factor's probability is uniform within the 0 ÷ 100% limits.

The frequency of the incoming reflected signals and their lag depend on the value of the astronomical unit A. Accumulating the difference energy (1) by analyzer channels corresponding to different values of A, and taking the corresponding lags $\tau$, we may obtain the value of the difference energy $\Delta W_\tau$ of the reflected signal in the assumption of different values of A.

Plotted is in Fig. 4 the result of such a processing. Along the abscissa axis are the values of the astronomical unit with 10 000 km intervals, and along the ordinate axis — the ratio $\sum \Delta W_\tau / \sigma_{\Delta W}$, where $\sum \Delta W_\tau$ is the sum of difference energies for the processed sessions taken by channels and time lags corresponding to the given astronomical unit; $\sigma_{\Delta W}$ is the dispersion of the quantity $\sum \Delta W_\tau$ determined according to

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* (from the preceding page).- According to optical observations, Mercury's rotation period is equal to 88 terrestrial days, which at sounding signal frequency of 700 mcps may cause a maximum widening of cho-signal spectrum by $\pm 10$ cps relative to the mean frequency.

this drawing's data. As may be seen from it, the maximum positive value of the ratio $\sum \Delta W_\tau / \sigma_{\Delta W}$ (equal to 2, 3) corresponds to the 149 600 000 km value of the astronomical unit. The negative overshoots at other values of the astronomical unit are caused by noises, for the difference energy (1) of the reflected signals must always have a positive sign in the absence of noises.

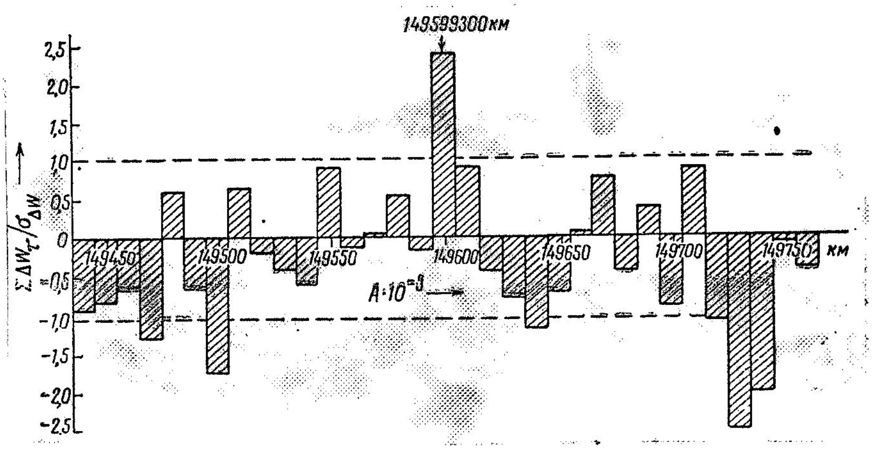


Fig. 4. Difference energy accumulation for various values of the astronomical unit.

In view of the smallness of the obtained value of $\sum \Delta W_\tau / \sigma_{\Delta W}$ the conducted experiment for radar location of Mercury, taken separately, cannot reliably guarantee the value of the astronomical unit determined through it. However, it further corroborates the value of the astronomical unit obtained during radar location of Venus in 1961 (see [1, 7, 8, 9] ).

## CONCLUSIONS.

The result of radar observations of planet Mercury do not contradict the results of measurements of the astronomical unit obtained during radar location of Venus in 1961 and provide for Mercury a reflection factor close to that of the lunar surface.

****** THE END ******

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